THE CROCKER ECLIPSE EXPEDITION FROM THE LICK OBSERVATORY, JUNE 8, 1918.

Some Eclipse Problems.

By W. W. CAMPBELL.

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Eclipse observers have always before them two principal questions:

What is the solar corona?

Why does the sun have a corona?

It must be confessed that the best answers at present available are far from satisfactory and complete. We have established many important facts, especially as to the nature of the corona, but these are more or less isolated facts, with suggestions here and there as to the relations of the facts to each other. That the progress made has not been greater is due to the tantalizingly short time available for observation. In the past twenty-one years I have had a total of twelve minutes in which to secure observations of the corona, and during four of those minutes—in Spain—the observations were made through thin clouds.

It is not a narrow interest which directs our efforts. The corona is a part of the sun, and we can never claim to know what the sun is until we understand all parts of it, including the corona, and the reasons for the corona's existence. The sunspots, the faculæ, the flocculi, and the prominences are undoubted evidence of great activity of movement in the sun's outer strata. It seems not too much to hope that a thorough understanding of the corona will contribute greatly to an understanding of the sun's circulatory system.

Again, it is not alone the more thorough understanding of our own sun which supplies the motive for eclipse study. Is there a corona around every sun? There may be; solar coronas may be plentiful throughout the universe, but we do not know. A complete understanding of our own star is certainly a pressing duty to the investigator who looks toward the understanding of the stars in general.

The Form of the Corona.

Near the end of last century eclipse observers recognized that the outline of the corona is a function of the sunspot phase. Our first slide (No. 1) illustrates well this general relationship. The coronas here shown, proceeding from right to left, are, first, that of 1889, at sunspot minimum; second, the corona of 1893, at sunspot maximum; third, the minimum corona of 1900; and fourth, the maximum corona of 1905. In all of these the sun's equator is nearly vertical with reference to the slide, and the sun's rotation axis is nearly horizontal. The phenomena in question are illustrated in a more interesting manner by the second and third slides of the corona on a larger scale. The circular corona (No. 2) is that of the 1893 eclipse, and the greatly elongated one (No. 3) is of the year 1900.

It is perhaps natural to expect that the polar streamers of the corona should be more extensive at times of great solar activity, as indicated by the maximum phase of spottedness, but that the equatorial streamers should be the longer at sunspot minimum would scarcely have been predicted.

It cannot be said, however, that the outline form of the corona is accurately predictable from the known phase of the sunspot-cycle. We photographed the corona (slide No. 4) with cameras of focal lengths varying from four feet to forty feet on June 8, 1918, at Goldendale, Washington. The spot phase was but a few months past the maximum, and we expected the corona to be essentially circular in outline. Our predictions were not fulfilled so satisfactorily as we had expected. Slide No. 5, an exposure of four seconds with a camera whose focal length was four feet, shows streamers extending out to approximately three solar diameters to the right and to the left, that is, to the west and east of the sun, whereas the streamers to the north and south (above and below) are very much shorter. The sixth slide is one obtained with the forty-foot camera, exposure four seconds; the departure from circularity of outline is very marked even for the inner corona. Does the circular type of corona prevail only during a short period of time at a well-defined phase of maximum spottedness, or is the relation of outline form to spot phase not very definite? Future eclipses should try to determine the relationship more precisely than we can be said to know it at present. The equipment needed for this work is inexpensive. Cameras of moderate length, say from four to seven feet, are abundantly powerful.

There has been no satisfactory hypothesis proposed to account for the undoubted relationship of coronal form and sunspot phase.

Relationship of Coronal Streamers to Other Solar Phenomena.

The relations of coronal structure to other phenomena of the sun, such as the prominences, sunspots, and faculæ, are subjects of inquiry with every corona recorded. Our slide No. 7, the eclipse of 1898 in India, shows clearly, and I think for the first time, the hooded forms of coronal structures which encircle some of the prominences. The following eclipse, that of 1900 in Georgia, did not show this feature, unless perhaps very mildly in the case of one prominence. The larger prominences in 1900 were certainly unattended by these hooded coronal forms. Later eclipses showed the occasional presence of this phenomenon, but not strongly, until we come to the eclipse of last year, when it was very marked indeed. Slide No. 8 is an exposure of one second on Seed thirty plates obtained with the camera of forty feet focus. Nearly all of the larger prominences and some of the smaller ones are enclosed by strong and well-defined hoods. There can be no doubt, I think, that the prominences and the curved streamers encircling them possess some kind of intimate relationship. The greater part of the inner corona recorded by this photograph consists of these curving streamers.

Slide No. 9 is a four-second exposure made with the same instrument. The most of the strong coronal structure here shown appears likewise to be under the control of, or to have intimate relationship of some kind with, the prominences which seem to lie at centers of controlling influence. Nearly all of the structure to the right of the sun is divided into three main compartments, each with a prominence at the central point of contact with the sun's limb.

Slide No. 10 is an enlargement showing one of these sections on a still greater scale. The division of this part of the corona into three sections by the two intervening vacancies is clearly marked.

The corona of 1893, at sunspot maximum, slide No. 11, does not show this interesting phenomenon to have been present. Why it should have been observed so much more conspicuously in 1918 than at other time remains unanswered.

My colleague, Dr. Moore, had attempted to correlate the main features of last year's corona with the prominences then visible and with the positions of sunspots and faculæ as they existed on the day of the eclipse. The Mount Wilson Observatory has generously lent its solar photographs secured on that day, and on several days preceding and following, for this purpose, and we gladly make due acknowledgment of our indebtedness. Lantern slide No. 12 illustrates the position of coronal structure, prominences, sunspots, and faculæ, at the instant of the 1918 eclipse, as measured roughly, or estimated, from the Mount Wilson observations obtained on the several consecutive days. The features on the front side and near the limb of the solar sphere are illustrated on the central circle of the slide, and the features thought to be on the rear side of the sun are set down on the right and left wings of the slide. The well-defined symbols represent the spots and the poorly-defined markings the faculæ. It cannot be said from this sketch that the prominences were situated above visible sunspots or faculæ. The hooded coronal forms therefore appear not to have been controlled from centers of disturbance coinciding with spots or faculæ. The vacancy in the coronal structure directly to the right of the sun is approximately in a plane passing through the observer, the center of the sun, and the group of spots and faculæ visible in the sketch to the right of the center, but, in view of the positions of the two principal prominences on the right edge of the sun, occupying the central points of their hooded structures, we seem not justified in looking further at present for a relationship between the vacancy in the coronal structure and the group of spots and faculæ. This group is really more than 40° from the sun's east limb.

Professor Perrine's coronal photographs of 1901, in Sumatra, recorded what he called a "disturbed" volume of the corona. It is shown in slide No. 13. Examining the photographs of the sun obtained on and near the day of the eclipse, he found that a prominent sunspot, in fact the only conspicuous sunspot known to be on the sun at that time, was situated very close to the sun's limb, and immediately under the center of the disturbance in the corona. The same slide shows a small prominence to the left of the sun—near the lower left edge of the slide—with a faint hooded enclosure.

This subject of relations between coronal structure and other solar phenomena is a very interesting and important one for eclipse observers of the future to hold in mind.

The Forms of Coronal Streamers.

The force which carries materials into the coronal region may be volcanic, as Schaeberle and others have suggested, or it may be chiefly radiation pressure, or a combination of these, or indeed a force of quite unknown nature. The arrangement of the coronal materials in the well-defined streamers may be a result of the sun's magnetic properties, as Bigelow and others have thought, but if so the principal features of the 1918 corona, especially to the east and west of the sun, would require that merely local magnetic fields be in control. The polar streamers certainly are very suggestive of control by the sun's general magnetic forces, but this influence does not seem to be the prevailing one in the remaining coronal structure.

Motion within the Corona.

Inasmuch as the corona of one eclipse is different in every detail from that of the succeeding eclipse, we cannot doubt the existence of motion and change within the corona. An interesting question is, how rapidly do these changes occur? Can they be detected from a comparison of coronal photographs of the same eclipse, obtained at two or more stations distributed along the path of totality? This is a problem which eclipse observers have held in mind during several decades. The eclipse of 1905 seemed especially promising for an attack upon this problem. Crocker expeditions from the Lick Observatory were located in Labrador, in Spain, and in Upper Egypt, with the principal motive the obtaining of coronal photographs separated by the considerable intervals of time, with a view to the detection of motion in coronal structure during the intervals. Clouds prevented observation in Labrador; excellent photographs were obtained through thin clouds in Spain, but the Egyptian photographs were not well-defined, owing to disturbances in the atmosphere, probably arising from the highly heated desert conditions of the middle afternoon. Slide No. 14 compares an interesting region of the corona as photographed in Spain and Egypt, with cameras of identical dimensions, focal lengths forty feet. The great prominence, it will be noticed, was sharply defined in Spain (on the left), but the definition was poor in Egypt (on the right). Many details of prominence structure changed during the interval of approximately seventy minutes, but we are not concerned especially with changes in prominences, as this is one of their well-known characteristics which may be and has been studied successfully on many days of the year at home. A comparison of the coronal structure in the region of the prominence is made difficult by the good definition in one case and the mediocre definition in the other, but there is no doubt that many changes occurred in the coronal details while the moon's shadow was passing from Spain to Egypt. Dr. Perrine and I were unable to say, however, that the motion was outward or inward, or that it was due to decrease of brightness for certain details and increase for others. Expressed differently, there were evident changes of detailed structure, but these changes were apparently haphazard rather than due to motion of illuminated materials systematically outward or inward. Nevertheless, that changes did occur in the interval is certain.

Dr. Moore has compared our 1918 coronal photographs obtained in the State of Washington with copies of those obtained by the Lowell Observatory Expedition, in Kansas, thanks to Director Slipher's courtesy. The scales are different, and the atmospheric conditions were poorer in Kansas, so that comparisons of our originals with copies of the Lowell photographs are difficult and unsatisfactory. Nevertheless, many changes in details are noted to have occurred in the interval of one half hour. Some of these seem to be the result of motion outward and others of motion inward, but we are not prepared to say that one or the other motion is the prevailing tendency.

The search for changes in coronal structure evidently remains one of the most interesting eclipse problems of the future. The photographs secured at points as widely separated in time as possible should be made with instruments of long focus, forty feet or more, and under conditions as nearly identical as practicable. Slow plates, such as Seed 23, preferably of the non-halation type, or suitably backed to avoid internal reflections, should be used, and the program of exposures at the different stations should be of identical efficiency. The utmost pains should be taken to have the plates in perfect focus and the diurnal motion accurately allowed for. The camera should be so designed that heated air within the camera itself would not detract from the definition. There remains the factor beyond control, the different states of the atmosphere at the various stations, and this is a serious factor indeed, as will be recognized by every observer who has endeavored to compare measures of sharply defined photographs with others of the same object but less definite.

Copies of the photographs obtained in 1918 by the Lick Observatory have been distributed to other institutions known to be interested in the subject, and if a comparison of these with photographs obtained at other stations should reveal definite evidence of coronal changes in the intervals we shall be very pleased indeed.

Polarized Light in the Corona.

A study of the polarized light in the corona has long been recognized as of great importance. Much remains to be done in this field of inquiry. The photography of the corona through double image prisms (slide No. 15) has both advantages and disadvantages. The latter arise in part from the factor of chromatic aberration when utilizing coronal rays having a great range of wavelength values. The definition under these conditions is unavoidably not all that should be desired, and some uncertainty in the quantitative results necessarily follows. The method of inclined plane glass reflectors in front of the coronal cameras, as used successfully by Dr. Perrine (slide No. 16), has its advantages. In this slide the richness of polarized light in the corona is indicated by the greater vertical dimensions of the right hand image, and the greater horizontal dimensions of the left-hand image.

A point of first importance in any method of studying the polarized light consists in making sure that the apparatus itself does not introduce polarization, and thus vitiate and render uncertain the observational data. One should be especially on his guard when using quartz and possibly other optical pieces in any way. Before definitely adopting any form or design of analyzing apparatus, laboratory tests should be made to ensure that this apparatus may be trusted not to produce its own polarization effects.

The Spectrum of the Corona.

The spectrographic study of the corona at eclipses of the past two or three decades has led to tolerably definite ideas as to the quality of the coronal light. That there are shallow strata of incandescent gases overlying the photosphere and chromosphere of the sun is certain. However, the use of the term strata in this connection may be misleading. Some of the strata seem to be fairly uniform in thickness over large arcs of the sun's limb, or change their thickness very gradually in passing from one region to another, but in other cases the thickness is very irregular. Slide No. 17 is an exposure, effectively short, secured with a grating spectrograph in 1918, to record the so-called green coronal ring consisting of radiations with wave-length 5303A. The ring is seen to be "lumpy." Similar photographs of the ring at wave-length 4231A have shown it to be more nearly uniform in thickness. The principal condensations in the green ring are adjacent to prominences, but not in coincidence with them. In the illustration the positions of the principal prominences are indicated by the dotted line enclosures lying outside of the green ring. The positions of the 5303 maxima are indicated by the dotted line extending inward from the ring and bearing numbers indicating the north and south solar latitudes. The green condensations are slightly farther from the solar equator than are the adjacent prominences. If the condensations are related to the prominences, the relationship is not immediate and intimate. There is poverty of green material near the north and south poles of the sun.

The faint dark bands passing through the green condensations have been noted at earlier eclipses. The condensations are undoubtedly strengthened a little by the superposition of these bands of continuous light with the green ring. The origin of the continuous bands has been under discussion. It has seemed to me that the materials responsible for the green ring yield continuous radiations more abundantly than special radiations, for it must be remembered that the latter are condensed in the slender ring, whereas the faint continuous bands stretch from end to end of the spectrum. The energy represented by the green ring, and in fact by all the bright coronal rings, is exceedingly slight in comparison with the sum total of coronal radiations, and apparently represents but a small fraction of the radiations proceeding from the bright ring materials themselves. It has been suggested that the faint bands passing through the condensations in the green ring may proceed principally from prominences; and, again, that they may have had their origin in photospheric light passing through depressions in the moon's edge, owing to the exposures having begun too soon after contact II., or continued too close to contact III. I do not think the point has been well taken, for the relationship of the continuous bands to the green condensations is plainly evident, and there is no apparent reason why these condensations should be related to depressions in the moon's edge. Again, there is a considerable number of extant coronal spectrograms bearing upon the subject. Slide No. 18 is from Lockyer's photograph of 1905. The green coronal ring to the right contains a prominent condensation through which passes a strong band of continuous radiation. This band is shown on the left in the H and K calcium region of the same spectrogram. The band misses the calcium prominences very skilfully. In the same way the hydrogen images of the prominences on the same spectrogram do not show the continuous band as passing through them.

The coronal spectrograms of recent decades are essentially agreed that the continuous radiations of the bright inner corona are but feebly and inappreciably affected by Fraunhofer absorption, thus establishing, in my opinion, that the inner coronal materials are chiefly incandescent and supply us with radiations of their own, to which reflected or diffused photospheric light makes but a small addition. The spectrum of the outer corona, on the contrary, say regions lying ten or fifteen minutes, or farther, from the sun's edge, undoubtedly contains the Fraunhofer lines. The interpretation is that the outer corona is shining, possibly in part by its own light, but chiefly by virtue of the photospheric rays falling upon the outer coronal materials. Slide No. 19 was obtained in 1918. The broad spectrum is that of the sun itself. The spectrum of the corona to the west of the sun is in the upper narrow band. The green bright line is shown on the extreme right, and the ultra-violet bright line at 3601A is very close to the extreme left end. The bright points on the lower edge of the coronal spectrum are from the prominences. The radiations in two long bright lines at H and K undoubtedly originate chiefly in the prominences, and the great length of these lines is due to the diffusion of the calcium light in its own atmosphere. The exposure was in effect too short to record the spectrum of the outer corona. No dark lines are visible. Spectrograms secured by us at earlier eclipses have recorded dark lines in the outer corona.

Trustworthy observations of this kind require an absolutely clear sky. It is dangerous to draw conclusions from spectrograms obtained through light clouds. This is illustrated by slide No. 20, copied from the coronal spectrogram secured in Sumatra in 1901. The Fraunhofer lines are shown strongly in the outer corona, *and likewise upon the dark moon!* Much of the Fraunhofer effect is undoubtedly due to the diffusion of the sun's photospheric rays by the thin clouds which covered the sky at that time.

The observed polarization effects are in harmony with the spectrographic as to the nature of the continuous coronal radiations.

Rotation of the Corona.

A few observers have sought to determine the rotational speed of the corona as a Doppler-Fizeau effect, by measuring the accurate wave-lengths of the green bright line to the east and to the west of the sun. If the corona is rotating with a speed approximating that of the sun's underlying surface, then the corona adjoining the east limb of the sun should be approaching us at the rate of two km. per second, and the corresponding coronal structure west of the sun should be receding with an equal speed. It cannot be said that the observations for rotation have been successful, though the difference of observed wave-lengths is in the right direction. The chief difficulty lies in the apparent fact that the green line is not strictly monochromatic. Recalling the lumpy appearance of the green coronal ring, we should perhaps be prepared for the probability that there is motion within the green ring, such that the line as observed by us is widened by radial velocity differences, and not reliably measurable.

The Wave-lengths of the Coronal Bright Lines.

Much remains to be done in determining the accurate wave-lengths of the coronal bright lines, in preparation for the chemical identification of these lines. There are at least half a dozen coronal lines whose position in the spectrum are determinable, with suitable apparatus and care, much more accurately than they are now known. Probably the best procedure is the unambitious one of attempting to determine the position of only one line, or at most two neighbor ing lines, with one instrument, exposing with as high dispersion as good judgment dictates; covering with a narrow diaphragm the region of the plate occupied by the coronal line while impressing the appropriate arc or spark spectrum of an element, both shortly before and shortly after the total phase of the eclipse.

The Brightness of the Corona.

The photometry of the corona is a problem worthy of further attention, especially with reference to coördinating the laws of coronal brightness with the sunspot phase. Studies in this field should take into account the distribution of the coronal radiations throughout the spectrum. The contrasting of the spectral photometry of the outer, middle, and inner coronal structures is a most promising problem, and the preparing of suitable apparatus, on the basis of optical parts already existing in abundance, should be a simple matter.

The Flash Spectrum.

The so-called flash spectrum of the sun's edge at the second and third contacts should, in my opinion, be observed with instruments specially and carefully designed, and adjusted with great care, to obtain improved data as to the limiting depths of the strata responsible for the various solar absorption lines.

Contact Times.

The times of contact of sun and moon have been more extensively observed than any other eclipse phenomena. It has long seemed to me that the first and fourth contacts, that is, the instants of time when the moon's image first touches the sun's, and when the moon's image finally leaves the sun's, are not worthy of much attention, and our expeditions have taken no interest in them. The time of the first contact is bound to be uncertain. The observer who is watching for it suddenly realizes that the moon has covered a bit of the sun. How many seconds earlier the contact really occurred he does not know. He is simply aware that it has occurred, and several seconds of uncertainty are unavoidable. The fourth contact can be observed with considerably more accuracy, but a first contact of equal accuracy does not exist to balance it. The second and third contacts, on the contrary, can be observed quite accurately. Nevertheless, the brilliant points continuing to exist at contact II. after the general outline of the moon's edge has passed beyond the sun's corresponding edge, owing to depressions in the lunar surface—and similarly at contact III.—introduce some uncertainty. It seems to me that very valuable comparisons of the relative positions of the sun and moon could be obtained by a series of large-scale photographs, using cameras forty feet or more in length, made near contacts II. and III., under conditions carefully devised for reducing the brilliancy of the solar crescents and for the accurate recording of the observation times.

The Accurate Position of the Moon.

It is very advantageous to eclipse observers that meridian observations of the moon's position be made in months immediately preceding the eclipse date, as a basis for predicting the time when totality will begin at any station on the shadow path. The eclipse of 1918 came seventeen seconds of time earlier than the Nautical Almanacs had predicted three years in advance, three seconds later than Professor Tucker's recent observations of the moon's position had indicated, and two seconds later than the chronometer time set down on the program prepared an hour before contact II. for the guidance of the observers.

The Einstein Effect.

The search for the so-called Einstein effect has become an important eclipse problem. It is well known that recent hypotheses of the nature of light require that rays from distant stars on their way to the eclipse observer, and passing close to the sun's edge, should be drawn toward the sun in appreciable amount while passing through the sun's gravitational field. This would cause a minute displacement of the stellar images upon the photographic plate. Photographs of the region immediately surrounding the eclipsed sun were secured by the Crocker Expedition on June 8, 1919, and photographs of the same region of the sky were obtained with the same instrument set up at Mount Hamilton in January of the present year. If the Einstein effect is a reality, a comparison of the two sets of plates, one obtained with the sun in the field of observation, and the other with the sun absent, should show slight and systematic differences in the angular separation of pairs of stars on opposite sides of the eclipsed sun's position. Owing to war service on the part of our astronomer who secured the photographs for this problem at the eclipse, the plates have not yet been measured. It is hoped that they will receive attention in the month of May.

In securing both sets of Einstein photographs, the driving clock should be reliable, and the observer should "guide" in right ascension on a bright star in the immediate neighborhood of the sun. A guiding telescope of three, four, or five inches aperture and of focal length equal to that of the Einstein cameras and making an appropriate angle with the axes of the cameras, should be able to pick up the image of the selected bright guiding star a few seconds before contact II.

The Vulcan Problem.

In view of Dr. Perrine's results of searches for unknown bodies revolving around the sun, made under the auspices of the Crocker

Eclipse Expeditions to Sumatra, Spain, and Flint Island, it seems sufficient to let the progress of this problem in the immediate future depend upon the Einstein photographs of the sun's surroundings.

Other Eclipse Problems.

Many other eclipse problems, perhaps of lesser importance from the astronomical point of view, cannot be considered here for lack of time. It is hoped that enough has been said to show that total solar eclipses have raised difficult and interesting questions.

Lick Observatory,
University of California.